# NARRAGANSETT MARINE LABORATORY

# GRADUATE SCHOOL OF OCEANOGRAPHY

# UNIVERSITY OF RHODE ISLAND

Reference No. 63-1

ACOUSTICS PROJECT

## Seismic Refraction Investigations in Selected Areas of Narragansett Bay, Rhode Island

by

William B. Birch and Frank T. Dietz



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John A. Knauss

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# PREFACE

This paper (Technical Report No. 7A) is a condensation of Technical Report No. 7, N.M.L. Reference No. 61-5.

The seismic refraction data presented in these two reports complete the third phase of an investigation begun in 1955 for the purpose of making available sound transmission data, bottom sediment data, and geological structure data for certain areas of Narragansett Bay.

Sound transmission information has been reported in the following reports:


Shallow Water Explosive Sound Transmission Runs in Narragansett Bay, by F. T. Dietz, W. B. Birch, and C. V. Mulholland, N.M.L. Reference No. 57-3, 1957.

Shallow Water Explosive Sound Transmission Runs in Narragansett Bay (Addendum), by F. T. Dietz, W. B. Birch, and C. V. Mulholland, N.M.L. Reference No. 58-3, 1958.

Shallow Water Continuous Wave Sound Transmission Runs, by F. T. Dietz, W. B. Birch, and C. V. Mulholland, N.M.L. Reference No. 58-5, 1958.

Shallow Water Continuous Wave Sound Transmission Runs (Addendum), F. T. Dietz, W. B. Birch, and C. V. Mulholland, N.M.L. Reference No. 58-6, 1958.


Information on the local sediment types was given in:


Analysis of Cores from Ranges Able, Baker, Charlie, and Dog, Narragansett Bay - 1955, by C. V. Mulholland and F. T. Dietz, N.M.L. Reference No. 56-8, 1956.

A Direct Measurement of Sound Velocities in Narragansett Bay Sediments, by F. T. Dietz, C. V. Mulholland, and W. B. Birch, N.M.L. Reference No. 58-4, 1958.


The geographical areas investigated in this report are designated as Profiles 1 through 14. In the earlier reports mentioned above, these same areas have been called ranges Able, Baker, Charlie, and Dog. For clarification the following list is given:

| Present Report | | Previous Reports |
|---|---|---|
| Profiles 1, 2, 3, 4 | correspond to | Range Able |
| Profiles 5, 6, 7, 8 | correspond to | Range Charlie |
| Profiles 9, 10 | correspond to | Range Dog |
| Profiles 11, 12, 13, 14 | correspond to | Range Baker |

# Seismic Refraction Investigations in Selected Areas of Narragansett Bay, Rhode Island[1]

William B. Birch and Frank T. Dietz

*University of Rhode Island, Kingston*

*Abstract.* Seven reversed refraction profiles have been fired in four shallow-water areas in Narragansett Bay, Rhode Island. The results are presented in the form of reversed travel-time graphs and cross-sectional representations of the strata. Seismic velocities and layer depths are shown in tabular form. Three ranges of velocities were obtained: (1) sediment velocities varying from 1.54 to 1.77 km/sec; (2) intermediate velocities of 4.16 to 5.11 km/sec, associated with the Rhode Island formation; (3) high-speed velocities ranging from 5.54 to 6.46 km/sec, associated with a crystalline third layer. In the areas under investigation, the thickness of the sediment layer varies from about 14 to 52 meters, the thicker portions generally occurring in the northernmost area. The boundary between the sediment layer and the intermediate layer varies from 23 to 45 meters below mean low water. The intermediate layer varies in thickness from approximately 200 meters at the northern end of the bay to 58 meters toward the south. The boundary between the intermediate layer and the third layer ranges in depth from 85 to 340 meters below mean low water.

*Introduction.* During the summer of 1955, seismic refraction data were obtained for four shallow-water areas in the West Passage of Narragansett Bay, Rhode Island. In 1956, supplementary seismic measurements were made in the same areas. In this paper the results are summarized and presented in the form of reversed travel-time graphs and cross-sectional representations of the strata.

Narragansett Bay lies in the southeastern part of the state of Rhode Island and is a part of the Narragansett basin, a product of continental downwarping and subsequent deposition, which extends north and south in Rhode Island and northeastward into Massachusetts [*Shaler, Woodworth, and Foerste,* 1899]. The bay is bounded, and largely underlain, by the Rhode Island formation, a thick series of conglomerate, sandstone, schist, phyllite, and meta-anthracite [*Quinn,* 1952]. The Rhode Island formation is encircled by plutonic rock, chiefly granite [*Quinn and Oliver,* 1962]. In some locations the granitic rock is separated from the Rhode Island formation by the Pondville conglomerate, a thin strip of arkosic rock and quartzitic conglomerates [*Quinn,* 1952; *Nichols,* 1956]. However, the Pondville formation does not extend into the areas under investigation in this paper. The sedimentary beds of the basin were intensely deformed during the Appalachian revolution, resulting in the formation of complicated folds whose axes trend generally north in the bay area and northeast into Massachusetts.

The locations of the seven reversed profiles are shown in Figures 1 and 2. Three of the areas are in the West Passage of the bay in the Quonset Point region; the fourth in Greenwich Bay.

All references to depths in this paper are with respect to mean low water.

*The 1955 data.* Data were obtained from four reversed profiles, varying from 2.3 to 3.2 km in length. A conventional two-ship refraction shooting technique was used. Explosive charges consisted mainly of half-pound TNT-tetryl demolition blocks, detonated by U. S. A. special nonelectric blasting caps. Occasionally, 2½-pound charges of the same explosive were used. All charges were detonated on the bottom.

*1955 instrumentation.* A single Brush AX-58C hydrophone equipped with a WHOI type preamplifier was used as a receiver. The hydrophone was connected to a WHOI two-chan-

[1] Contribution 41, Narragansett Marine Laboratory, University of Rhode Island. This paper is based on part of a thesis presented by William B. Birch to the University of Rhode Island in June 1961 in partial fulfillment of the requirements for the degree of Master of Science in Physics.

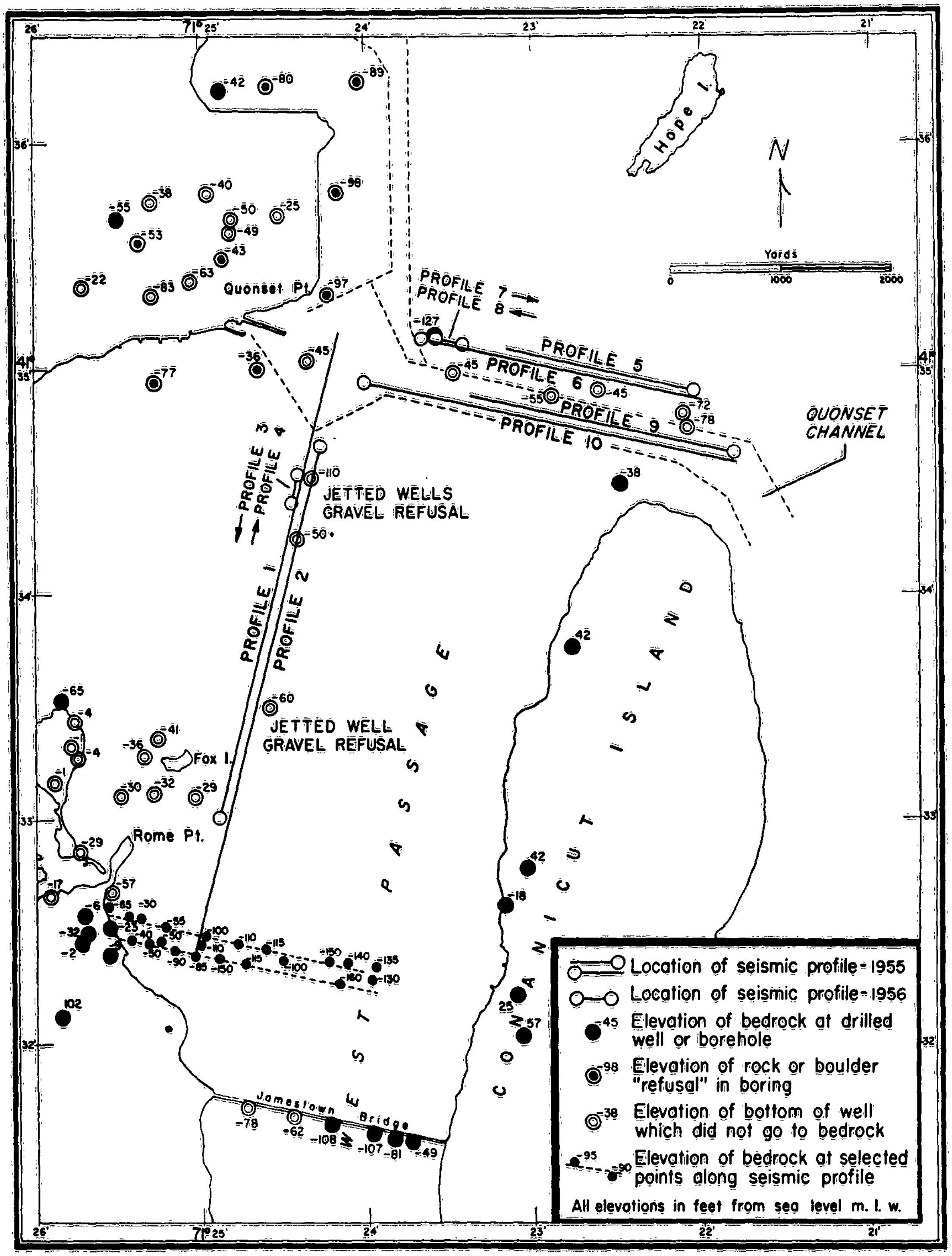


Fig. 1. Chart of Quonset Point area showing seismic profile locations and bedrock information

nel amplifier [*Dow*, 1952]. High- and low-pass electronic filters provided water wave and ground wave information, which was fed into two channels of a four-channel driver amplifier [*Dow*, 1952] and then into a Sanborn four-channel direct writing recorder. A broad-band signal

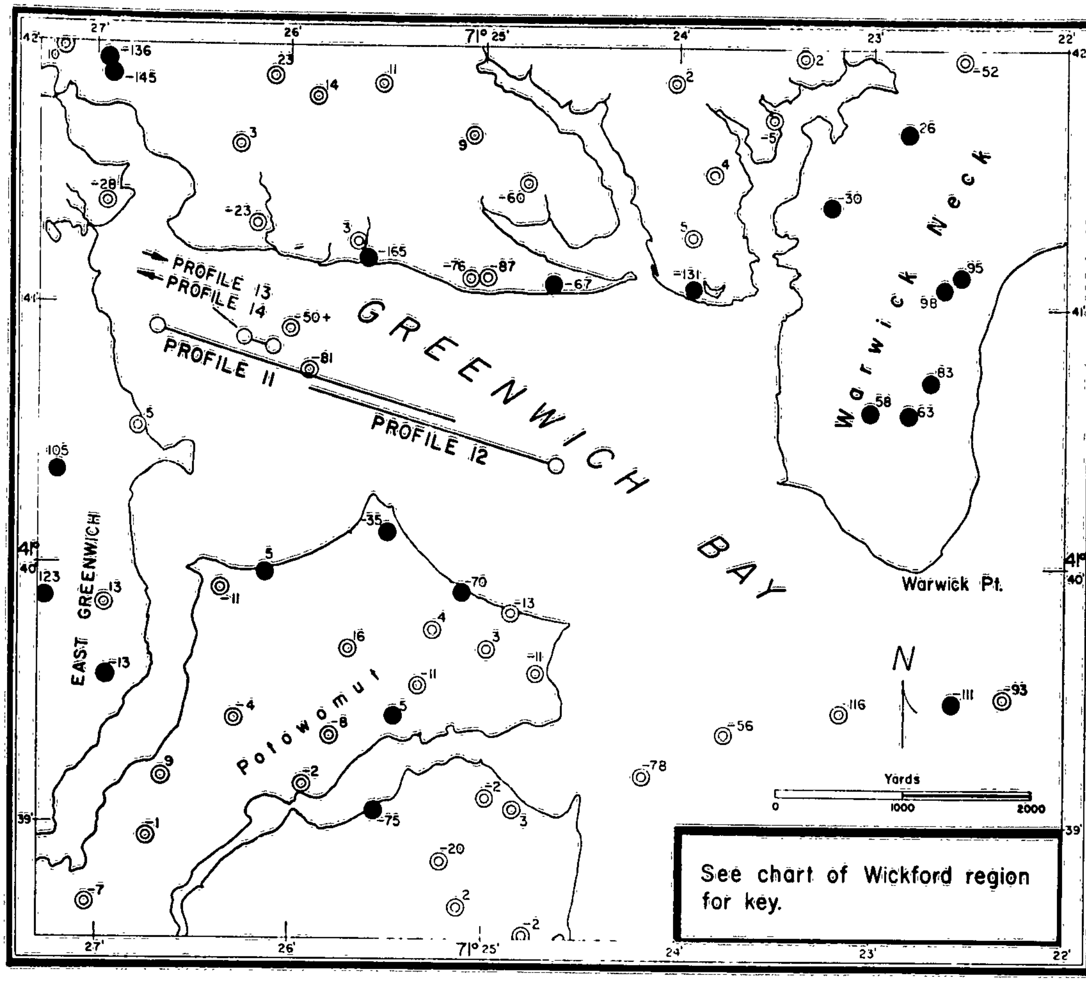


Fig. 2. Chart of Greenwich Bay area showing seismic profile locations and bedrock information.

was recorded on a third channel of the Sanborn recorder, and 1-second time ticks from a break circuit chronometer and also the radio-transmitted shot instant from the shooting ship were recorded on the fourth channel. The recorder was operated at its maximum paper speed of 100 mm/sec.

*The 1956 data.* Methods were designed to

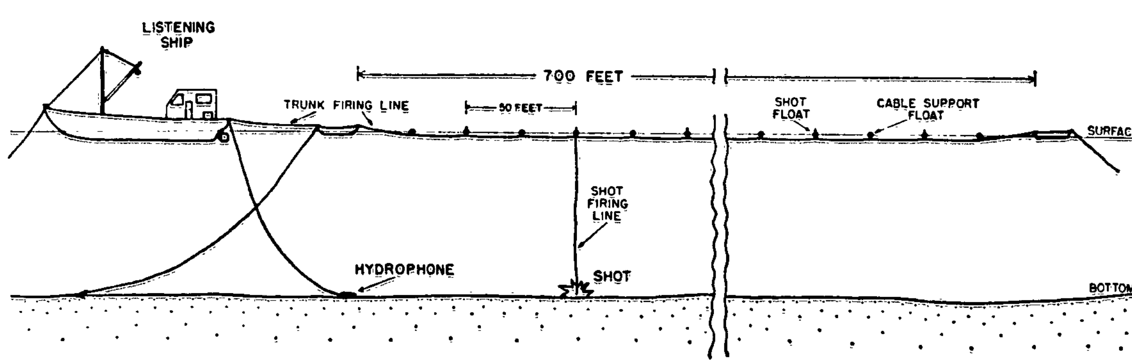


Fig. 3. Schematic diagram of shot cable.

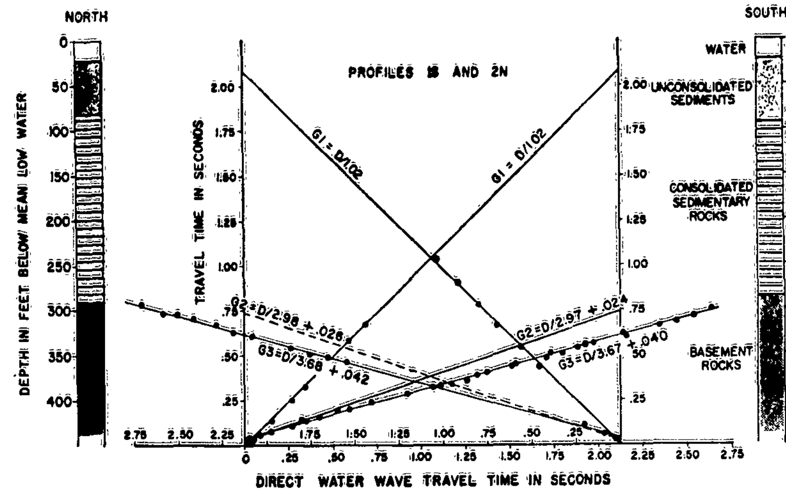


Fig. 4. Reversed travel-time graphs for profiles 1 and 2.

give more precise information about the sediment layer than were obtained from the 1955 data.

One vessel, the R.V. *Virginia*, and three skiffs were required for the 1956 work. A 'shot cable' was used, consisting of a 213.4-meter length of stainless-steel cable to which snap rings were attached every 7.6 meters. Taped to this cable was a length of two-conductor rubber-covered electrical cable to which a leader was spliced at every other snap ring. In practice, an explosive charge was connected to each leader in turn; as a result shots were spaced at 15.2-meter intervals. A metal ball float was attached to each snap ring by means of a short length of line and a snap hook, so that the entire cable floated about 0.3 meter beneath the water surface. The cable arrangement is shown in Figure 3.

The charges used were half-pound TNT-tetryl demolition blocks detonated by du Pont no. 6 electric blasting caps fired from the listening ship.

*1956 instrumentation.* A Brush AX-58C hydrophone and a two-channel WHOI amplifier were used. The broad-band output from one channel of the amplifier was split and fed into two channels of a Hathaway oscillograph camera, one channel being operated at a higher gain than the other. The output from the second channel of the WHOI amplifier was high-pass

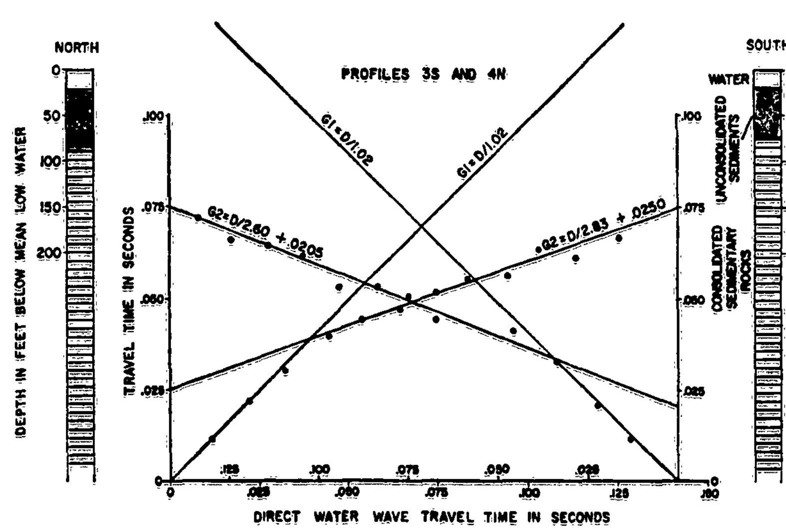


Fig. 5. Reversed travel-time graphs for profiles 3 and 4.

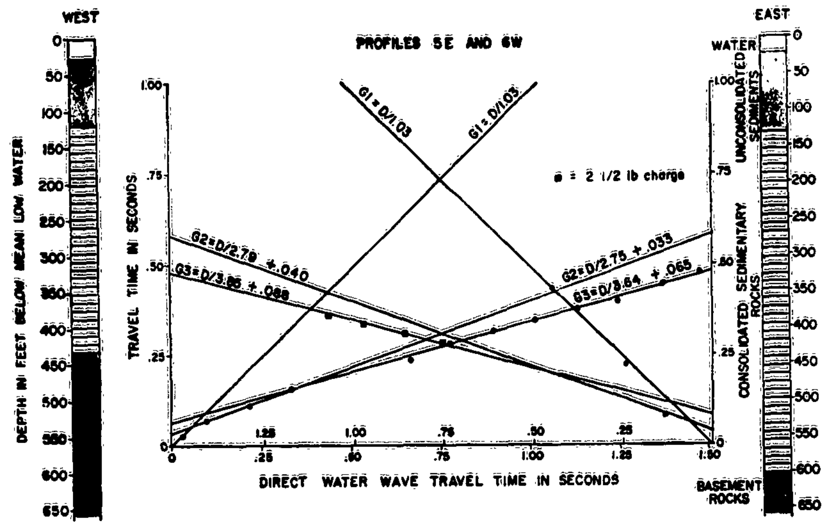


Fig. 6. Reversed travel-time graphs for profiles 5 and 6.

filtered, rectified, and fed into a third channel of the oscillograph camera. A crystal-controlled oscillator provided a source of precision 100-cps signal which was put on a fourth channel of the oscillograph for use as a timing reference. Detonation-time information was fed into a fifth channel of the camera. The camera was operated at a paper speed of 48 inches per second.

*Results and discussion.* Data were taken along profiles 1, 2, 5, 6, 9, 10, 11, and 12 in 1955. In Figures 1 and 2 the circle at the end of each of these profiles designates the position of the listening ship during the firing of that particular profile. The reversed travel-time graphs for these profiles are shown in Figures 4, 6, 8, and 9. The letters N, S, E, and W following the profile numbers on the graphs indicate the receiver position with respect to the shooting ship.

The 1956 data were obtained from reversed profiles 3, 4, 7, 8, 13, and 14, all 213.4 meters long. The profiles are shown in Figures 5, 7, and 10. Although the position of the listening ship differed in the 1955 and 1956 profiles, it was assumed that the sediment velocity information

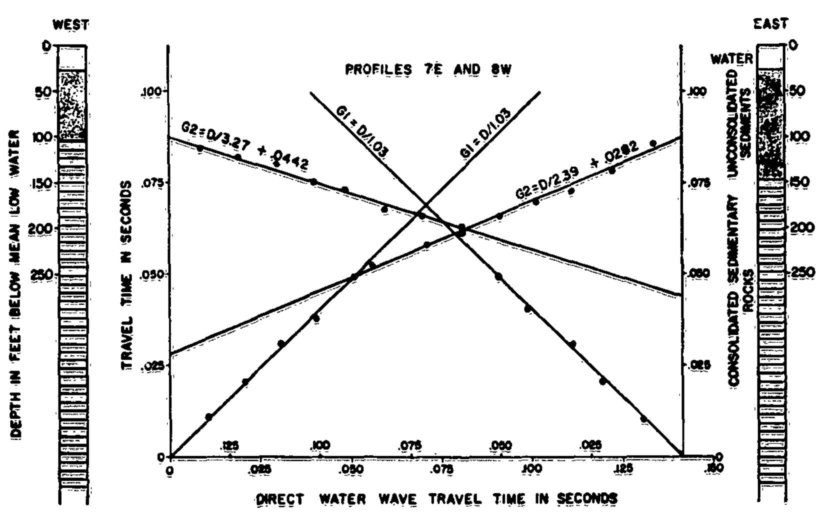


Fig. 7. Reversed travel-time graphs for profiles 7 and 8.

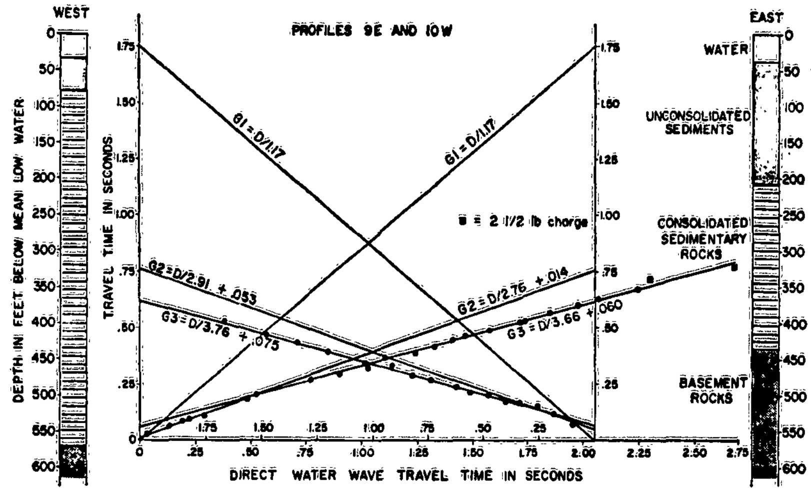


Fig. 8. Reversed travel-time graphs for profiles 9 and 10.

would be representative of the area in question. The arrows in Figures 1 and 2 point toward the position of the listening ship during the firing of a particular profile.

The calculations followed the method of *Ewing, Woollard, and Vine* [1939]; the results are summarized in Table 1. In general, the depths from the 1955 data are considered accurate to 10 per cent; the 1956 depths are accurate to within 5 per cent. A 2 per cent error in velocity determinations is indicated.

Profiles 1 through 10 were taken in the same general area. The bottom is essentially flat, and the water depth varies from about 6.4 to 8.4 meters. Exceptions are profiles 9 and 10, which were fired in the Quonset channel where the water depth averages 10.4 meters at mean low water. The near-surface sediments range from gravelly sand to silt and mud [*Mulholland and Dietz,* 1956].

Two refracting horizons were in evidence over most of the profiles. Sediment velocities of 1.54 to 1.77 km/sec were determined. The 1.77-km/sec velocity for the Quonset channel area was determined from a minimum number of points.

The velocity of the intermediate layer varies

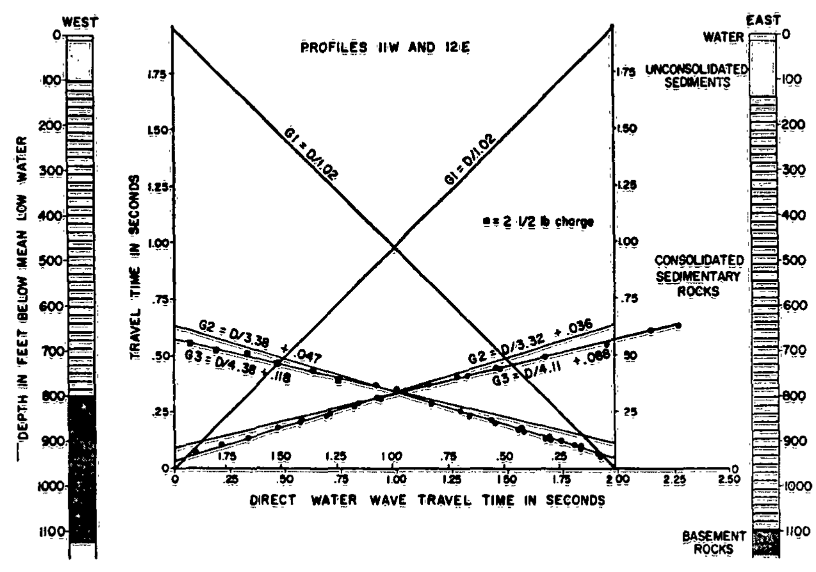


Fig. 9. Reversed travel-time graphs for profiles 11 and 12.

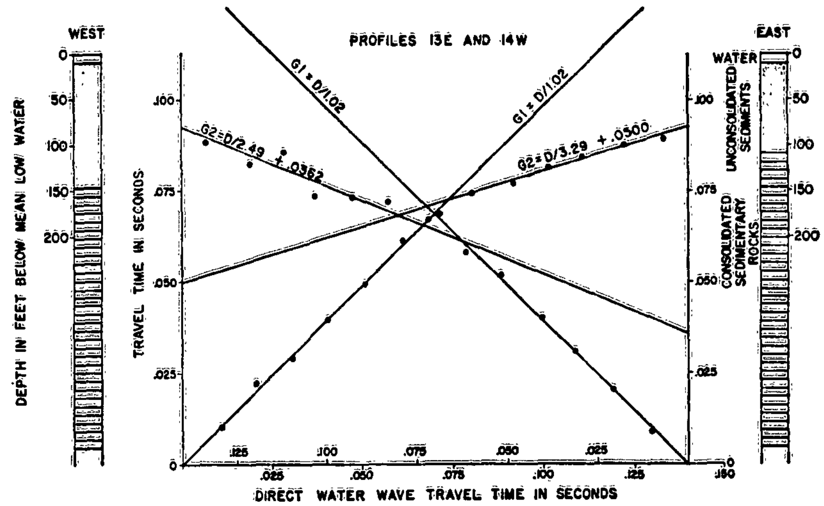


Fig. 10. Reversed travel-time graphs for profiles 13 and 14.

from 4.08 to 4.48 km/sec. There were too few points to establish an intermediate velocity line for profile 1. However, the results of a reflection survey made by the Gahagan Construction Corporation of New York in 1954 (private communication) in the Rome Point area indicate a reflecting horizon at a depth of about 28 meters. This depth and the reverse point from profile 2 were used to construct an apparent intermediate velocity line of 4.48 km/sec.

It was also necessary to use an approximate method in drawing the G2 line for profile 9, since most of the points fell along the G3 line. A line was drawn from the reverse point of the G2 line of profile 10 through the point on the G3 line closest to the origin. This line gave a minimum apparent velocity of 4.40 km/sec, and the zero time intercept gave a maximum apparent thickness to the second layer.

High-speed velocities ranged from 5.54 to 5.61 km/sec for the third layer. The high-speed arrivals were well defined for the long ranges, but no high-speed arrivals were seen over the short ranges.

Measured from mean low water, the depth to the upper refracting horizon varies from

TABLE 1. Summary of Seismic Results

| Profile | Depth to Upper Horizon,* meters | Depth to Lower Horizon, meters | Surface Layer Velocity, km/sec | Intermediate Layer Velocity, km/sec | Third Layer Velocity, km/sec |
|---|---|---|---|---|---|
| 1 | 28 | 86 | 1.54 | 4.48 | 5.54 |
| 2 | 26 | 85 | | | |
| 3 | 23.2 | | 1.54 | 4.08 | |
| 4 | 27.1 | | | | |
| 5 | 40 | 180 | 1.55 | 4.16 | 5.63 |
| 6 | 35 | 130 | | | |
| 7 | 44.5 | | 1.56 | 4.16 | |
| 8 | 31.1 | | | | |
| 9 | 63 | 130 | 1.77 | 4.28 | 5.61 |
| 10 | 24 | 170 | | | |
| 11 | 32 | 250 | 1.55 | 5.11 | 6.46 |
| 12 | 43 | 340 | | | |
| 13 | 33.5 | | 1.55 | 4.31 | |
| 14 | 44.8 | | | | |

* All depths are with respect to mean low water.

about 23 to 63 meters. The depth to the lower refracting horizon ranges between 85 and 180 meters.

Profiles 11, 12, 13, and 14, in Greenwich Bay and running generally east and west, lie in shallow water 2.4 to 3.1 meters deep at mean low water. The bottom sediments are uniformly fine, being composed of materials of silt size or smaller, of which the first meter or so is extremely soft. The sediments at the ends of profiles 11 and 12 are sandy mud [*Mulholland and Dietz*, 1956].

A sediment velocity of 1.55 km/sec was determined for this area. For the 1955 profiles 13 and 14 an intermediate velocity of 4.31 km/sec was found, which agrees with the corresponding velocities for the southern areas. An intermediate velocity of 5.11 km/sec was computed from the 1955 data, along with a high-speed velocity of 6.46 km/sec. These velocities are between 15 and 20 per cent higher than the average velocities for the corresponding layers in the southern areas. The accuracy of the 1955 figures is uncertain, however, because the shallow water made water wave arrivals difficult to determine.

On the basis of these figures, the depths of the upper refracting horizon below mean low water varies from 32 meters at the west end of the profile to 43 meters at the east end. The lower refracting horizon occurs at a depth of 250 meters at the west end and at 340 meters at the east end.

*Conclusions.* The data discussed in this paper resulted from a sound transmission experiment, rather than from a detailed seismic survey; therefore, widespread coverage of the bay was not achieved. The Narragansett Bay area is structurally complex, and it is difficult to make generalizations about the substructure on the basis of a limited amount of data. There is, however, definite evidence that three layers exist: an unconsolidated sediment; a consolidated intermediate layer; and a third layer, probably granitic.

In the area between Quonset Point and Rome Point, along the western shore of the West Passage, the sediment layer is essentially uniform in thickness. Between Quonset Point and the northern tip of Conanicut Island the sediment thickens from west to east. It decreases in thickness along a line northward from the tip of the island. Private communications (U. S. Army, Corps of Engineers, 1956; Parsons, Brinkerhoff, Hall, and MacDonald, Engineers, 1954; Gahagan Construction Corporation, 1954) indicate an appreciable thickening of the sediment towards the east. East of Rome Point and along the line of the Jamestown Bridge the sediment layer thickens toward the middle of the West Passage and then thins out as the west shore of Conanicut is approached. A thickening of the sediment southward from Rome Point is also indicated. Sediment thicknesses for profiles 5 to 10 are supported by results of a 'sparker' survey in the Quonset channel area (First U. S. Naval District Public Works Office, private communication, 1961) and by borehole information (Fink, WHOI, private communication, 1957).

In the Greenwich Bay area, profiles 11 and 12 indicate a thickening of the sediment layer from west to east. This trend is further substantiated by a series of boreholes across the mouth of Greenwich Bay (U. S. Army, Corps of Engineers, private communication, 1956) as well as by jetted wells [*Nixon*, 1954; *Dietz, Mulholland, and Birch*, 1958].

Along the range between Quonset Point and Rome Point, the intermediate layer shows no appreciable change in thickness. Between Quonset Point and the northern tip of Conanicut, along profiles 5 and 6, the intermediate layer thickens from west to east, whereas along profiles 9 and 10 a thinning of the layer occurs. These trends point to a thickening of the intermediate layer northward from the tip of the island.

In Greenwich Bay the intermediate layer is considerably thicker than in the Quonset area, and it increases in thickness in an easterly direction.

The intermediate velocities are probably associated with the Rhode Island formation and agree with velocities reported by *Birch* [1942], *Faust* [1951], and *Hughs and Cross* [1951] for Pennsylvanian rocks of this type. However, no specific velocities are available in the literature for the various kinds of rock in the bay area.

A. W. Quinn (private communication, 1961) suggests that the high velocities might be characteristic of a firmly indurated and metamorphosed layer of the Rhode Island formation such as is found near the approach to the Jamestown Bridge. The possibility that the high velocities are associated with granitic rock should also be considered, since the geologic maps [*Quinn*, 1952; *Quinn and Oliver*, 1962] indicate a granitic bedrock beneath the surrounding land areas. Both types of rock might be expected to exhibit similar seismic properties.

*Acknowledgments.* The work described in this paper was supported by the Office of Naval Research under contract Nonr-396(04). We are indebted to Mr. C. V. Mulholland for preparation of the drawings and to the personnel of the Narragansett Marine Laboratory who assisted in the field program. Appreciation is also extended to Dr. Robert Frosch of Hudson Laboratories, Columbia University, for providing the galvanometer camera used in the 1956 phase of the work.

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